

Climate change tendencies observable in the rainfall measurements since 1950 in the Federal Land of North Rhine-Westphalia and their consequences for urban hydrology

Tendances du changement climatique observées dans les mesures pluviométriques en Rhénanie-du-Nord-Westphalie (Allemagne) depuis 1950 et leurs conséquences pour l'hydrologie urbaine

Thomas Einfalt¹, Markus Quirnbach², Gerd Langstädtler³, Bernd Mehlig⁴

- (1) hydro & meteo GmbH & Co. KG, Breite Str. 6-8, D-23552 Luebeck (einfalt@hydrometeo.de)
- (2) dr. papadakis GmbH, Werksstr. 15, D-45527 Hattingen (m.quirnbach@drpapadakis.de)
- (3) aqua_plan GmbH, Goethestr. 5, D-52064 Aachen (gl@aquaplan.de)
- (4) State Agency of Conservation, Environment and Consumer Protection, Postfach 101052, D-45610 Recklinghausen, (Bernd.Mehlig@lanuv.nrw.de)

RÉSUMÉ

Le changement climatique fait partie des modèles climatiques, mais peut-on déjà détecter une variation dans les mesures ? Pour le land de Rhénanie du Nord-Westphalie, une analyse systématique des mesures à partir de 1950 a été menée afin de déceler des tendances potentielles et des modifications du régime pluviométrique au cours de ces 59 années. Après une vérification détaillée, menant à l'élimination des données non-plausibles, les mesures de plus de 600 stations ont été utilisées. Par la suite, des valeurs standard comme la quantité de pluie annuelle, la quantité de pluie mensuelle, le nombre de jours par an sans pluie ou en dessus d'un certain seuil ont été calculées et évaluées. Les résultats montrent qu'il y a déjà eu des modifications du régime pluvieux au cours des 59 dernières années. Ces changements ont été hétérogènes dans l'espace. Les conséquences pour l'hydrologie urbaine sont discutées et le besoin en solutions de dimensionnement plus flexibles est exprimé.

ABSTRACT

Climate change is present in climatological models – but did we already observe changes in the past measurement data? For the state of North Rhine Westphalia, the rainfall measurements since 1950 have been systematically analysed in order to find out whether there have already been trends and whether the behaviour of rainfall has changed in time. More than 600 station series have been screened for use in the project and quality controlled. Implausible data were discarded. For the analysis, standard values such as yearly sums, half-yearly sums, monthly sums, number of dry days, number of days with precipitation above a threshold, partial time series and extreme values statistics have been calculated and evaluated. Results show that also in the past 50 years, changes in precipitation regime could be observed. These changes have been regionally different. Consequences for urban hydrology include a development of more flexible design approaches.

KEYWORDS

Climate change, rainfall analysis, rainfall series, urban flexible design

1 INTRODUCTION

Climatological models have been analysed for their importance for urban drainage applications by several authors (e.g. Madsen et al., 2009 ; Beecham / Onof, 2006). Past observable trends have been subject to investigations in different European Countries, e.g. UK (Jenkins et al., 2009), Denmark (Madsen et al., 2002), Hamburg (Schluenzen et al., 2008), the ENSEMBLES project (van der Linden et al., 2009), and Southern Germany (KLIWA, 2006). However, an analysis of long and quality controlled historical time series for a large network of stations combined with a comparison to regional climate projections of four regional climate models with a particular focus on small time steps (< 1 day) has not been attempted before. A project comparison has not been performed in this project.

In the scope of the research project “Studies of heavy rainfall in North Rhine – Westphalia based on extreme statistics” (ExUS), supported by the Ministry of the Environment and Conservation, Agriculture and Consumer Protection (MUNLV) of North Rhine – Westphalia (NRW), different objectives had to be fulfilled : the collection, quality control and analysis of measured rainfall at all stations within NRW since 1950 ; the extreme value analysis of the remaining data, detection of trends in extreme rainfall, yearly rainfall and shorter time periods ; the comparison to regional climate change projections of four different climate change models for the time periods of the historical data as well as for two future time periods, 2021 – 2050 and 2071 – 2100. Methods of the above mentioned studies have guided the ExUS evaluations.

The results of the studies on the climate change models have been described in Quirnbach et al. (2009) and Langstädtler et al. (2009). This article focuses on the procedures, aims and results from the analysis of the measured precipitation data of close to 600 stations in NRW (34 000 km²) for the time period 1950 - 2008. Neither the climate projections nor the comparison to results from other studies are the major topic of this paper.

2 DATA BASE

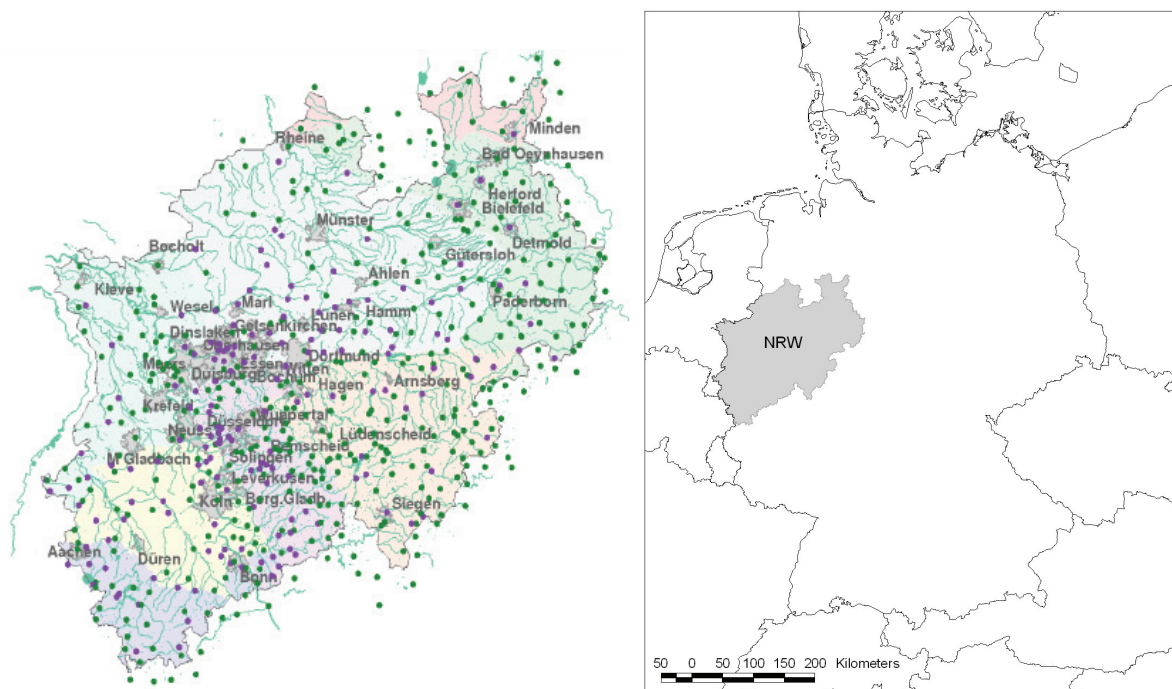


Figure 1. Left: Stations used for the analysis: 412 daily stations (green), 176 continuous stations (violet); Right : the region of North Rhine-Westphalia within Germany

2.1 Continuous stations

More than 210 stations have initially been available for the project. The number of the stations had to be reduced if the stations had been observed for less than 20 years, had identical data, large gaps were present, or data did not pass the quality control, see below. Finally, data from 176 stations

remained for further analysis and with the attribute “good quality” (figure 1).

Continuous stations in NRW are operated by many different actors, the main ones are the state environmental agency (LANUV) itself and the 16 water authorities, a lesser extent is operated by the German Weather Service (DWD) – not used in this study – and by the cities in NRW.

2.2 Daily stations

More than 550 stations with daily values have been available for this project. These data have been supplied by the water authorities, the LANUV and the DWD. After quality control and check for observation length, there were data from 412 stations which have been included in the analysis in the project.

2.3 Data quality control

Basically, rain gauge data quality control passes from items that are easy to check to more complex ones. In practice, this means that initially, existing gaps in the data are excluded from further treatment, then features on the data of one station only are investigated, and finally an intercomparison between the data from several rain gauges is performed.

The structure from simple check elements at the top, down to more complex ones, as proposed above, comprises the following steps (Einfalt et al. 2006):

- Detection of gaps in the data: The detection of gaps in the data mainly serves to exclude the gap interval of a station to be used for comparison to other stations.
- Detection of physically impossible values : Such data consist of negative rainfall values and very high intensities, e.g., more than 5 mm per minute in a moderate climate. These values have been excluded from further evaluation.
- Detection of constant values : Constant values over a certain time are an indicator of unusable data which may be either due to bad digitization or to missing values in case of digital registration.
- Detection of values above set thresholds: For predefined durations, it is useful to indicate when the measurements are above statistically rare values, e.g., higher than an event occurring every hundred years. Useful durations comprise 5 minutes, 15 minutes, 60 minutes and 1440 minutes (one day). Such thresholds were defined in order to identify “interesting” events, which have been carefully checked manually.
- Detection of improbable zero values : these values can be detected at a station if all surrounding stations have significant rainfall and the stations are close enough to each other.
- Detection of unusually low values: the daily sum of a station has been compared to the daily sums of the neighbouring stations. If the surrounding stations recorded significantly more rainfall than the selected one, the measurement of this station has been checked manually.
- Detection of unusually high values: the daily sum of a station has been considered to be too high if the surrounding stations recorded significantly less rainfall than the selected one and if a convective rainfall could be excluded. This was assumed to be the case between October and March.

The quality control procedure helped to eliminate stations that did not have reliable data and thus reduced the overall number of stations from 214 to 176. More detailed results of this control can be found in Podlasly et al. (2009).

3 DATA ANALYSIS

3.1 Basics: time intervals analysed

The overall period 1950 to 2008 was subdivided into four 30-year long intervals:

- 1950 – 1979
- 1961 – 1990 (international climate reference period)
- 1971 – 2000
- 1979 – 2008

Additionally, the data of the whole time period have been analysed. The time intervals of 30 years' duration have been selected in order to be in line with WMO standards and provide results comparable to regional climate change models. Initial analyses have also been performed within ExUS (Quirnbach et al., 2009).

The analysis took place for yearly sums, half-yearly sums, monthly sums, climatological values (number of dry days, number of days > 10 / 20 / 30 mm) and for extreme value statistics.

3.2 Trend analysis

Trends in the data were examined with two methods: the Mann-Kendall test and the linear regression with t-test. The first test has the advantage that it detects trends in data with any underlying data distribution – it does not, however, compute the size of a trend. The main advantage of the second test is that it produces a value for change as well as its significance – on the other hand it requires the basic data to be normally distributed. Normal distribution can be assumed for yearly sums and for half-yearly sums. All other analysed values like monthly sums, number of days with high precipitation or partial series of the data are usually not normally distributed. Therefore, the size of a trend cannot be checked for significance.

Trends by any of the methods were considered to be significant if the level was higher than 80%. The other thresholds employed were 90%, 95% and 99%.

3.3 Yearly sums

Yearly sums are the most common parameters for intercomparison between rain gauge stations, regions and continents. Therefore, these values are very important for any additional work with the data.

3.3.1 Paradoxal results on yearly sums

The trend comparison between the time intervals 1950 – 1979 (figure 2) and 1979 – 2008 (figure 3) showed for both intervals decreasing trends for parts of North Rhine Westphalia, e.g. in the most southern parts in the Eifel mountain region. The trend for the whole period 1950 – 2008 (figure 4) however showed an increase of rainfall. This apparent contradiction was subject to a more detailed analysis before any further analyses were performed.

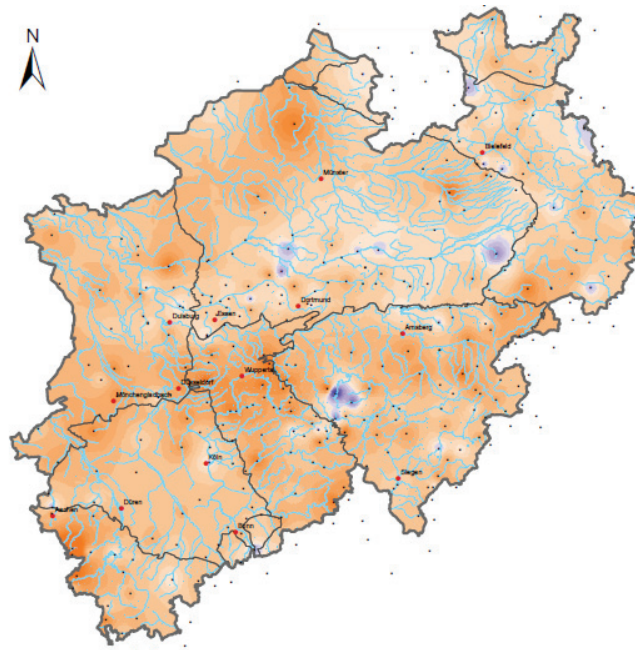


Figure 2. Trend in yearly sums 1950-1979 – blue = increase of rain; orange = decrease of rain

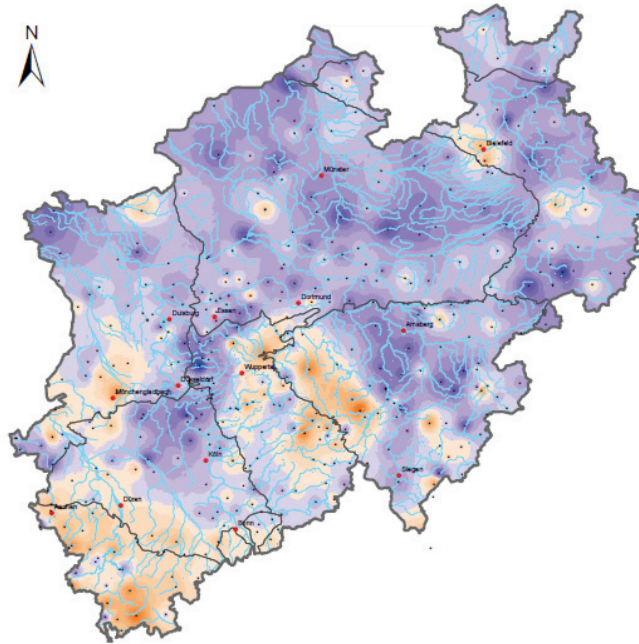


Figure 3. Trend in yearly sums 1979-2008 – blue = increase of rain; orange = decrease of rain

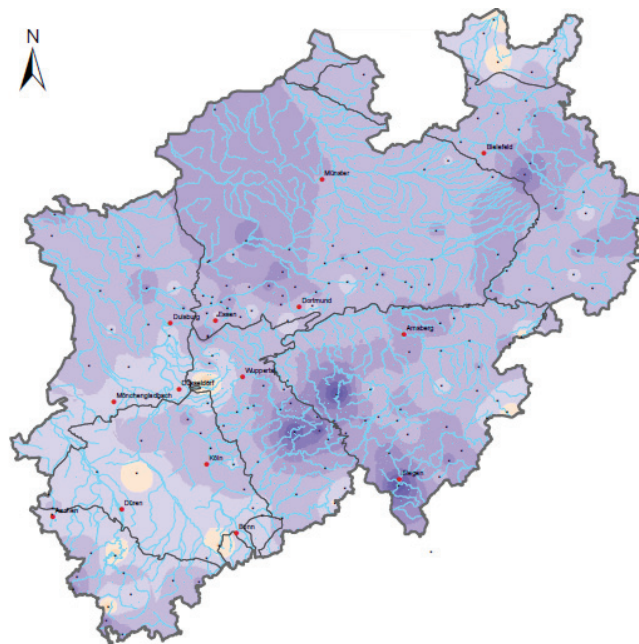


Figure 4. Trend in yearly sums 1950-2008 – blue = increase of rain; orange = decrease of rain

The yearly sums at station Nieheim DWD (figure 5) explain this behaviour: Since the time interval 1971 – 1980 recorded less rain than any other ten year period between 1950 and 2008, this time period plays a major role for trend analysis of shorter time intervals. This even more since the ten years 1981 – 1990 had more rain than average: an early 30-year period will therefore show a negative trend, as well as a late 30-year period, although the overall trend may be positive. So a trend estimation for the period 1950 – 1979 leads to a negative trend (-51 mm/decade), as well as the estimation for the period 1979 – 2008 (-5 mm/decade). However, the overall time interval 1950 – 2008 exhibits a growing trend (3.5 mm/decade).

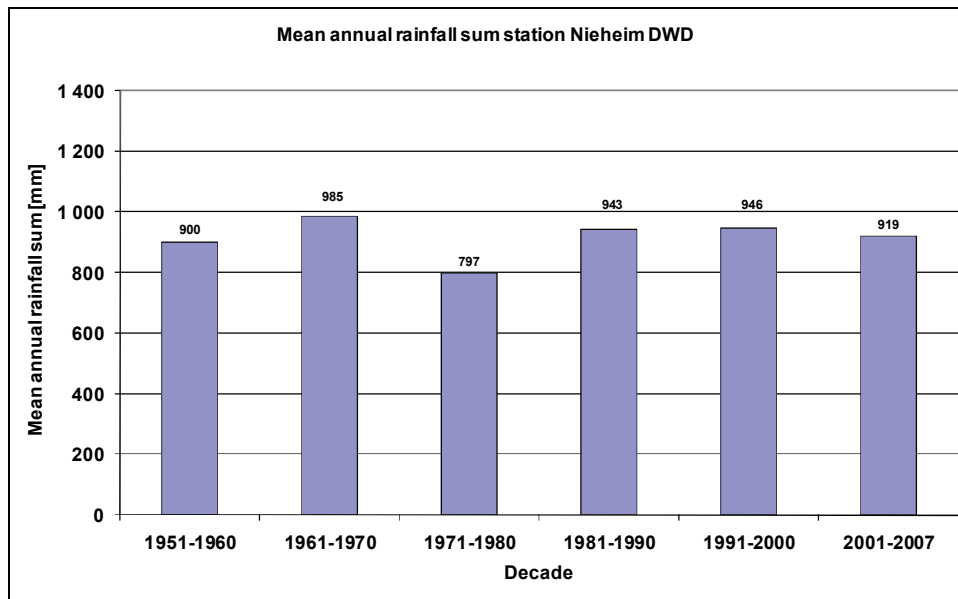


Figure 5. Yearly sums of station Nieheim DWD for decade intervals

3.3.2 Consequences for further work

The example illustrates that a 30 year time interval is not representative enough to deduce a trend from the data. As a consequence from this finding, trends were only determined from the whole range of the years 1950 to 2008, not for parts of this long time interval.

3.3.3 Result of yearly sum analysis

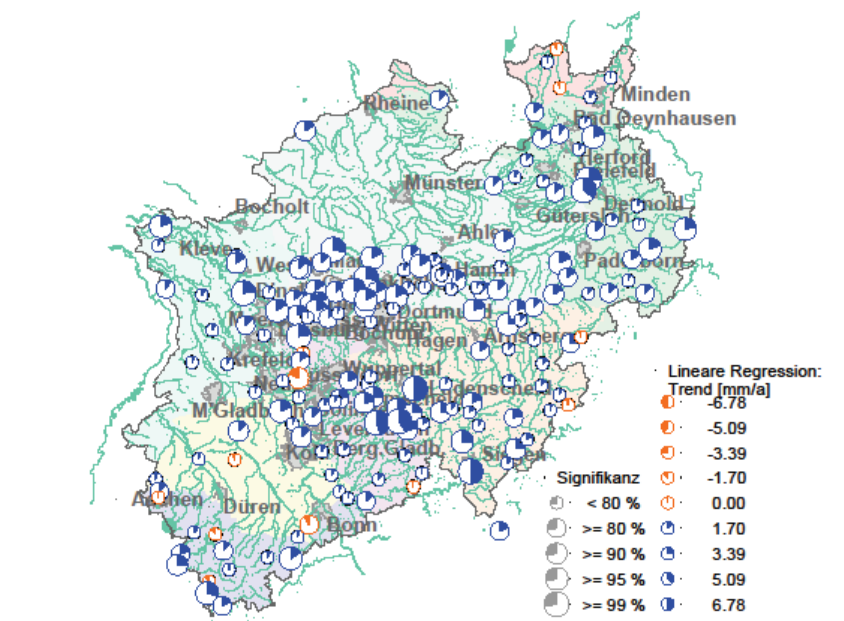


Figure 6. Trend in yearly sums for the time interval 1950 – 2008, linear regression test

The results for the yearly sum analysis over the complete time period of 1951-2008 shows that for most stations an increase of the yearly rainfall has been observed, being significant in more than 50% of the cases.

Figure 5 illustrates the outcome in using clocks, i.e. filled circles : the filling of the clocks explains the magnitude of the observed trend in mm/year (see legend), while the size of the clocks shows its significance level.

3.4 Winter sums

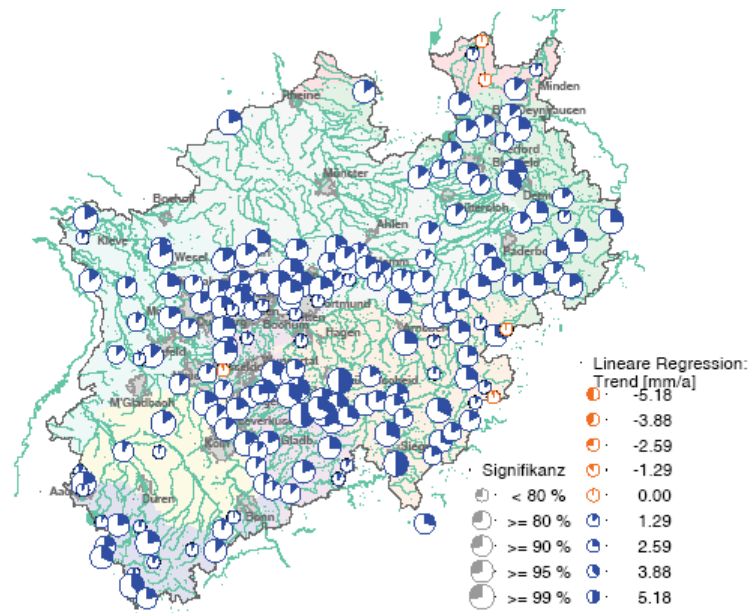


Figure 7. Trend in winter sums for the time interval 1950 – 2008, linear regression test

Winter sums showed a clear tendency to growing values which in 82% of the stations was significant, in 71% even for the 90% significance level. Figure 7 shows a clear regional difference where trends in the hilly regions on the southern edge of NRW and in the Ruhr area are more significant and higher than in the Rhine valley or the flat area around Muenster.

3.5 Summer sums

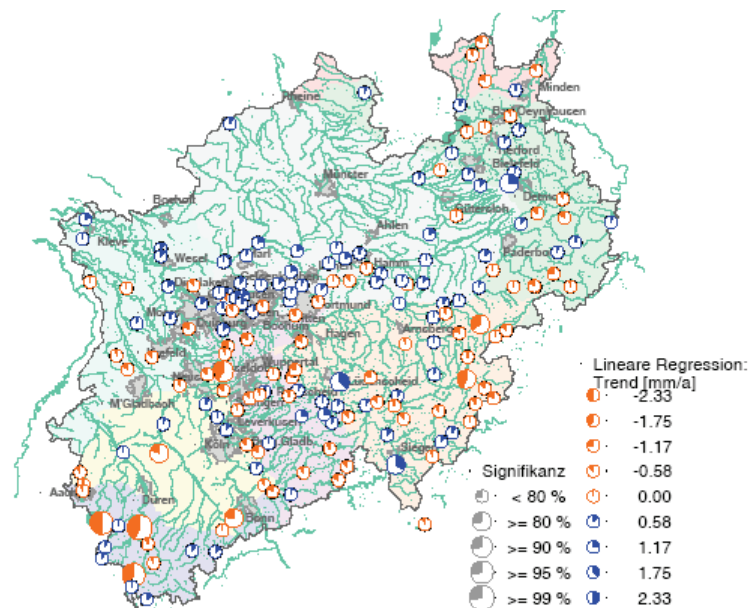


Figure 8. Trend in summer sums for the time interval 1950 – 2008, linear regression test

In summer, rainfall showed a completely different behaviour. Less than 10% of all stations showed a significant trend, and there was no clear tendency to increase or decrease either (figure 8).

3.6 Monthly sums

A significant trend could be observed at many stations (> 20%) for the months of January, February, March (all increase), and August (decrease). To a lesser extent, a significant trend was observed at over 10% of the stations additionally for the months of July (decrease), September, October and November (all increase). Figure 9 shows the direction of the trend as arrow and the percentage of

stations with a significant trend as intensity of the colour background. White background colour is equivalent to no significant trend. Since monthly values usually are not normally distributed, a trend analysis by linear regression producing a trend in mm/a is not applicable.

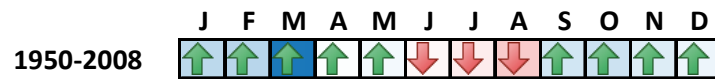


Figure 9. Trend in monthly sums for the time interval 1950 – 2008, Mann-Kendall test

3.7 Climatological analysis values

The analysis of climatological key values comprised the the evaluation of the number of days with the following attributes:

- Dry days
- Days with > 10 mm
- Days with > 20 mm
- Days with > 30 mm

The results of this analysis followed surprisingly well the direction already observed with the yearly values.

Looking at whole hydrological years, in many urban areas the number of dry days has increased while at the same time this number has decreased in some mountainous areas. So for dry days, there is no clear pattern for NRW when looking at complete years. For winter periods, there has been a clear uniform reduction of dry days, whereas in summer months they have increased.

On the other hand, the number of days with at least 10 or 20 mm per day has significantly increased over the last over 50 years, and this could be observed for the whole state area, and clearly for winter months, less pronounced but visible for summer months.

3.8 Partial time series analysis

Before extreme value statistics, the partial time series were analysed. The focus was on potential differences between different duration classes over the time. Such differences, e.g. the number of elements in a specific year for the partial time series of 5 minutes as compared to the one of 120 minutes can be an indicator for change. Such a change, however, does not need to be due to climate modification, but can in many cases be attributed to the modification of measurement devices, e.g. the replacement of a siphon type gauge by a tipping bucket or a weighing gauge.

Primary results were the exclusion of several gauges from the detailed analysis because they did not show a homogeneous behaviour over the duration classes over time.

Secondary results were the increase of the number of short term heavy rainfall recordings in the last years. This result still has to be verified on hidden device effects and on significance.

3.9 Extreme value statistics

No clear pattern could be detected in extreme value statistics. This can be due to the technique to analyse statistics of growing length (e.g. 1989-2008; 1979 – 2008; 1969 – 2008), but also to the precondition for such analyses of a constant mean without trend. This precondition may be questioned, and therefore the methodology may not be applicable for such evaluation.

4 CONCLUSIONS

The results show that climate has been changing in the last decades. The changes have been different for different regions, for different parameters observed and for different levels of significance. Many stations did not show a significant climate change signal, however.

The current state of information shows that changes in the climatic behaviour have already occurred at numerous places in the last 50 years, and regional climate models show that they are – in a regionally different manner – likely to be accentuated in the recently started century. Since reliable data for hydrological applications in the future are not available, design has to be flexible: strategies being able to respond to beyond design situations, e.g. urban flooding will be more and more beneficial for communities. Examples with this philosophy have been proposed by projects like URBAS (Einfalt et

al., 2009) where the design of floodways for extreme rainfall events (flash floods) with considerable surface flow has been presented. Similar “no regret”-strategies will also prove their use in future design in order to respond to challenges posed by climate change effects.

Further investigations will be undertaken to give detailed recommendations for different actors in how to deal with climate change effects within the BMBF supported project *DynAKlim* (www.dynaklim.de) which will run from July 2009 until June 2014.

5 ACKNOWLEDGEMENTS

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LIST OF REFERENCES

- Beecham, S., Onof, C. (2006). A statistical analysis of the non-stationarity of Australian rainfall measurements. *7th International Workshop on Precipitation in Urban Areas*, St. Moritz, Switzerland, 7-10 December, ISBN 3-909386-65-2.
- Einfalt, T., Hatzfeld, F., Wagner, A., Seltmann, J., Castro, D. and Frerichs, S. (2009). URBAS: forecasting and management of flash floods in urban areas. *Urban Water Journal*, 6:5, 369 — 374.
- Einfalt, T., Jessen, M., Quirnbach, M. (2006). Can we check raingauge data automatically? *7th International Workshop on Precipitation in Urban Areas*, St. Moritz, Switzerland, 7-10 December, ISBN 3-909386-65-2.
- Jenkins G., Perry M., Prior J. (2009) *The climate of the UK and recent trends*, Met Office Hadley Centre, Revised edition, January 2009, ISBN 978-1-906360-05-4.
- KLIWA-Heft 8: *Langzeitverhalten der Starkniederschläge in Baden-Württemberg und Bayern*, 93 S., ISBN 3-88148-412-4, Offenbach 2006
- Langstädtler, G., M. Quirnbach, T. Einfalt, B. Mehlig (2009) ExUS NRW – Statistical extreme value examinations of storm rainfall in North Rhine-Westphalia. *8th International Workshop on Precipitation in Urban Areas*, 10-13 December, 2009, St. Moritz, Switzerland.
- Madsen, H., Mikkelsen, P.S., Rosbjerg, D. and Harremoës, P. (2002) Regional estimation of rainfall-intensity-duration-frequency curves using generalised least squares regression of partial duration series statistics, *Water Resources Research*, 38(11), 1239, doi: 10.1029/2001WR001125.
- Madsen, H., Arnbjerg-Nielsen, K., Mikkelsen, P.S. (2009). Update of regional intensity-duration-frequency curves in Denmark: tendency towards increased storm intensities. *Atmospheric Research* 92, 343-349.
- Podlasly, C. and T. Einfalt (2009) NIKLAS – A new tool for automatic quality control of time series data. *8th International Workshop on Precipitation in Urban Areas*, 10-13 December, 2009, St. Moritz, Switzerland.
- Quirnbach, M., Papadakis, I., Einfalt, T., Langstädtler, G., Mehlig, B. (2009). Analysis of precipitation data from Climate model Calculations for North Rhine-Westphalia. *8th International Workshop on Precipitation in Urban Areas*, 10-13 December, 2009, St. Moritz, Switzerland.
- Schluenzen, K. H., Hoffmann, P., Rosenhagen, G., Riecke, W. (2009). Long-term changes and regional differences in temperature and precipitation in the metropolitan area of Hamburg. *Int. J. Climatol.*, DOI: 10.1002/joc.1968.
- van der Linden P., Mitchell, J.F.B. (eds.) 2009: *ENSEMBLES: Climate Change and its Impacts: Summary of research and results from the ENSEMBLES project*. Met Office Hadley Centre, FitzRoy Road, Exeter EX1 3PB, UK. 160pp.